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WADC TECHNICAL REPORT 54-472
PART 2

DEVELOPMENT OF AUSTENITIC IRON-BASE SHEET ALLOY

ROY R. ROTHERMEL

CRUCIBLE STEEL COMPANY OF AMERICA

MAY 1956

WRIGHT AIR DEVELOPMENT CENTER

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MAY 1956

MATERIALS LABORATORY
CONTRACT No. AF 33(616)-2047
PROJECT No. 7351

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Carpenter Litho & Prtg. Co., Springfield, O.
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FOREWORD

This report was prepared by the Crucible Steel Company of America Research and Development Laboratory, Pittsburgh, Pennsylvania under Contract No. AF 33(616)-2047. The contract was initiated under Project No. 7351, Metallic Materials, Task No. 73512, Development of Austenitic Iron Base Sheet Alloy, and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Lt P. A. Santoli acting as project engineer.

This report covers work conducted from October 1954 to December 1955.

ABSTRACT

Results of the investigation of the weldability of a type II, AD30 alloy (conducted in the welding laboratory of the contractor) indicate that this material can be welded when adequate measures are taken to limit stresses set up during welding and where proper protection from the atmosphere is afforded the material during welding.

Satisfactory welds were made in representative types of weld joints by the metallic arc process using types 310 and 312 mod. (2-3% Mo) electrodes and by the inert gas process using AD30 filler.

Satisfactory welds were obtained by the butt flashwelding process.

Bend test results of various welded specimens show good ductility, an evidence of formability of a welded section in the as-welded, solution treated condition.

Short time tensile test results indicate welded specimens to have strengths (at a 1500°F testing temperature) comparable to the AD30 base material.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. R. WHITMORE
Technical Director
Materials Laboratory
Directorate of Research

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DEVELOPMENT OF AUSTENITIC IRON-BASE SHEET ALLOY

I. INTRODUCTION

This is the summary technical report on Contract No. AF33(616)-2047, change order No. C1(56-396), covering the period 15 October 1954 through 31 December 1955 on the weldability of AD30 sheet alloy. The initiator of the work on this contract is Lt P. A. Santoli, USAF (WCRTL-3).

The purpose of this investigation was to study the weldability of sheet material of one of the more promising of the Type II steels, AD30, the approximate composition of which is as follows:

C	Mn	P	Ni	Cr	Mo	N	Fe
.50	8.0	.20	8.0	20.0	1.6	.20	Bal.

The first supplementary report of this weldability investigation summarized the results to that time as follows:

Alloy steels of the AD30 analysis and two experimental heats of similar analysis containing .17 and .24 P were difficult to butt weld by the inert gas welding process, although a type 312 filler wire occasionally produced welds free from cracks. Alloy steels containing .12 P or less were readily weldable by this process.

By means of the metallic arc process, the AD30 and five experimental steels containing .013 to .24 P could be welded, without cracks, when a type 312 Mod. (2-3% Mo) electrode was used.

Further, when an edge joint was employed, crack free welds of AD30 sheet could be obtained.

The weldability tests, the results of which were summarized in the first supplementary progress report, were conducted in one of the plant facilities of the contractor. Since the completion of this initial phase of the welding program, the contractor has established a welding laboratory,

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staffed by welding personnel and furnished with new welding equipment, so that a fresh and advanced approach to the weldability of AD30 sheet alloy could be undertaken.

The purpose of this present investigation is to develop a welding procedure which will consistently produce crack free welds in AD30 steel.

II. MATERIAL

All of the steels were prepared as induction melted ingots, the analyses of which are shown in Table I.

Steel 1, AD30, was made up as a one ton heat and steels 2 to 5, inclusive were made up as 15 lb. ingots.

All material prior to welding was solution treated at 2150°F for 1/2 hour, air cooled and sand blasted to remove scale formed during heat treatment.

In addition, some welded test plates were aged at 1550°F for 16 hours and air cooled.

III. EQUIPMENT

Welding equipment employed during the manual inert gas and metallic arc welding processes consisted of a motor-generator unit and a d.c. selenium rectifier; each used in conjunction with a high frequency attachment.

An automatic inert gas tungsten arc welding head, with power supplied by the d.c. rectifier, was also used.

Preheat, when used, was applied manually with an oxy-acetylene torch.

IV. PROCEDURE

As this phase of the investigation was concerned primarily with the development of a welding procedure to produce crack free welds, the general method followed was to determine what factors affected weldability and to establish control measures to minimize detrimental effects.

The weldability tests were conducted, initially, by butting two test pieces together and clamping them to a copper backing bar. The sizes of the test specimens were 2 in. x 6 in., 2 in. x 12 in. and 6 in. x 12 in., the welded plate being formed by butting two test specimens along the larger dimension.

Tests involving the manual inert gas tungsten arc process were made with AD30 filler wire and type 312 filler and the metallic arc process utilized types 310 and 312 mod. (2-3% Mo) electrodes.

Non-destructive tests were performed on the various welded specimens using a dye-penetrant indicator.

A. FACTORS AFFECTING WELDABILITY

During both phases of this investigation, it was found that short lengths of welds (three to four inches long) were easily made provided the proper electrode was used. However, when longer welds were attempted, cracking and distortion became prevalent. Because the AD30 alloy has a lower thermal conductivity than, for example, type 304 stainless, it was expected that welding stresses would be high in the AD30 alloy due to the high thermal gradients existing in the weld area. This was evidenced by the fact that during the welding of a twelve inch section, which was first tack welded lightly in several places, the tacks would break after welding had progressed three to four inches. On the other hand, if the tacks were made at least one inch long and one-eighth inch thick, neither the tacks nor the base material cracked during welding. However, welding stresses were sufficiently high to produce a marked local yielding (buckling) in the base metal around the tacks. Therefore, to reduce this gradient, preheat was applied to the plates prior to welding. Of the several ranges of preheat investigated, it was found that 450-550°F range was the most effective in reducing distortion and was low enough to be practical to use in fabrication.

Also, it was found necessary, in the control of distortion, to regulate the total heat input during welding. Therefore, the smallest diameter electrode at the lowest current setting together with as rapid a forward welding speed which would effect complete penetration were used in the tests. Some of these values are shown in Table II. Of considerable aid in attaining complete penetration at these settings was the beveling of the test plates so that the resultant joint was a 90° included Vee with a 1/32 in. root nose and a 1/16 in.-1/8 in. root opening. Further, the use of a water cooled backing bar was investigated, but not in conjunction with preheat. Distortion was reduced but the water cooled bar was adjudged impractical for welding contoured sections, and tests using this device were discontinued.

Another factor which is prevalent during welding of thin sheet material (.105 in. and under) and is sometimes confused with an inherent hot short condition of the material is atmospheric attack of unshielded portions of the weld area while the area is still extremely hot. This attack is most noticeable on the under side of butt welds and on the opposite legs of fillet welds, where the electrode coating cannot afford protection or where inert gas from the welding torch cannot reach. Therefore, a series of tests were conducted in which more adequate shielding was provided. Inert gas flow rates were increased, although not too greatly so as to counteract the minimum welding current. Also, for both inert gas and metallic arc welding, tests were made in which the undersides of the butt joints were coated with a flux conforming to MIL-F-7586.

B. WELDED SPECIMENS

Having determined proper electrodes and control measures to minimize distortion and eliminate cracking, the next step was to weld several representative types of joints of AD30 alloy sheet to demonstrate the weldability of this material.

The first of these specimens, Fig. 1, is a tube 3 in. long, 2 in. I.D. and .06 in. wall of AD30 alloy. Using a square butt joint, zero root opening, the tube was welded by the manual inert gas tungsten arc process, with no filler wire addition. There was no evidence of cracks when the weld was inspected by the dye-penetrant method.

A combination of edge joints is shown in Fig. 2. Again, this material is AD30 alloy, .06 in. thick, and the longest weld is approximately 4 in. The welds were made by the manual inert gas process using AD30 filler wire. Flux was applied to the inside corners. Penetration is complete with no evidence of cracking inside, or out, after inspection of the weld.

A fillet weld is shown next in Fig. 3. The material is steel No. 4 (Table I) and the pieces prior to welding measured 2 in. x 12 in. x .065 in. thick. The fillet welds were made by the manual metallic arc process using 3/32 in. dia. type 312 mod. (2-3% Mo) electrode. Flux was applied to all surfaces prior to welding. There was no evidence of cracking when the weld was inspected.

Another fillet weld is shown in Fig. 4 which demonstrates the welding of a thin to a thick section. The thin leg is AD30 material, .06 in. thick, while the base is steel No. 3 (Table I) and is approximately 3/8 in. thick. Welding was done by the manual metallic arc process using 3/32 in. dia. type 312 mod. (2-3% Mo) electrode. There is no evidence of cracking in the weld after inspection.

The next section shown, Fig. 5, is a combination of fillet and butt joints, and represents a rather severe restraint test. The material is AD30 alloy, .06 in. thick. Welding was done by the manual inert gas process using AD30 filler. Flux was applied to the under side of the piece prior to welding. Preheat of 450°F was applied and maintained during welding. There were four cracks, each approximately 1/16 in. long, apparent after dye-penetrant inspection. Two cracks were in fillet welds and two were in the area where all welds meet. However, after repair welding and re-inspection, no cracks were apparent which demonstrates the ease with which this material can be repair welded.

Finally, the last section to be welded was the tube shown in Fig. 6. The tube is 16 in. long, approximately 4-1/2 in. I.D. and .06 in. wall and made from AD30 alloy. The weld joint was a square butt, zero root opening. Welding was done by the manual inert gas process using AD30 filler wire. The tube was welded in 2 passes; the first layer was an edge fusing weld, with filler wire being added where needed to prevent burn through. The second layer was a fill-in weld filler wire being applied the entire length. Flux was applied to the inside of the tube prior to welding. Penetration is complete. There were no indications of cracks when this weldment was inspected by the dye-penetrant method, although there is one indication of surface porosity at approximately the midpoint of the weld.

C. AUTOMATIC WELD TESTS

Several weld tests were made on AD30 alloy using an automatic inert gas tungsten arc welder. The welding variables are shown in Table II. The welds showed no evidence of cracking after inspection.

D. FLASHWELDING

Butt flashwelding tests were conducted by Battelle Memorial Institute under a sub-contract let by Crucible Steel Co. of America.

The tests were made on AD30 alloy. Three of five flashwelded specimens showed no evidence of cracking.

V. TESTS

A. NON-DESTRUCTIVE TESTS

Non-destructive testing was confined to the use of a dye-penetrant method of detecting cracks and porosity which are exposed at the surface. This method of detection was deemed sufficient as any cracks occurring in welds appeared in one surface or both. Also, several microexaminations of welded structure failed to reveal internal microfissuring on specimens which showed no cracks externally. Further, in the few isolated instances where porosity was detected, this was attributed to welding technique rather than the base material.

In general, since the cracks when present were 1/32 in.-1/16 in. long, a binocular microscope was used to detect the indications.

B. WELD BEND TESTS

As any fabrication of AD30 alloy sheet would probably be done with the steel in the solution treated, as-welded condition, weld bend tests were included in the program as a means of evaluating weld ductility. It is apparent in Figs. 7, 8 and 9 that welds made with AD30 and type 312 mod. (2-3% Mo) electrodes have ductilities comparable to those of types 308 and 310 weld deposits. The bend tests shown in these figures were in the as-welded condition, after the base material was solution treated. Fig. 10 shows bend tests in material that was aged (1550°F, 16 hrs., air cool) after welding. Ductility in these welds is negligible.

C. MICROHARDNESS SURVEY

A microhardness survey was made on a section of AD30 sheet which was welded by the manual inert gas process using AD30 filler. The material, prior to welding, was solution treated at 2150°F for 1/2 hr. followed by air cooling. The survey showed the base material to have a hardness of 22-23 Rc (converted) and the weld deposit to have a hardness of 26-27 Rc. The highest hardness attained in the heat affected zone was 30 Rc.

Another portion of this weld was aged at 1550°F for 16 hours and air cooled. A microhardness survey of this section showed a hardness of 35-36 Rc in the base material, an average hardness of 26 Rc in the weld metal and a low of 26 Rc in the heat affected zone.

D. TENSILE TESTS

Room temperature tensile tests results for various welded sections are shown in Table III. The material was first solution treated, welded, then aged at 1550°F for 16 hours and air cooled.

E. SHORT TIME TENSILE TESTS AND STRESS RUPTURE TESTS

The results of some short time tensile tests and stress rupture tests are given in Tables IV and V. Data for base material are also given for comparison.

VI. SUMMARY AND CONCLUSIONS

During the course of the present investigation of the weldability of the type II, AD30 alloy, which was undertaken in the recently established welding laboratory of the contractor, the following observations and results have been obtained:

1. AD30 sheet alloy can be welded if proper measures are taken to control distortion and to provide an adequate shielding for weld metal and base material at the high welding temperature. Preheat to 450-550°F and controlling heat input during welding lessened the tendency of the material to distort.

   Providing adequate gas shielding and using a flux conforming to MIL-F-7586 aided in eliminating cracking in the base metal during welding.

2. Several representative types of joints were welded to demonstrate the weldability of AD30 sheet alloy. In only one joint, in which restraint was severe, was there evidence of cracks and these were removed by repair welding.

3. Bend tests of welded specimens of solution treated material showed good ductility, an indication that welded sections can be readily formed or bent in this condition (solution treated).

4. Short time tensile test results indicate welded specimens to have strengths (at a 1500°F testing temperature) comparable to the AD30 base material. Rupture life of welded sections is lower than that of base material.

5. The various test results indicate that either type 310 or 312 mod. (2-3% Mo) electrodes or AD30 filler wire can be used satisfactorily in welding AD30 sheet alloy.

6. Results obtained by a sub-contractor indicate that AD30 alloy can be butt flash-welded satisfactorily.

TABLE I

Type AD30 steels used in weldability investigation

Steel	Type	C	Mn	P	Si	Ni	Cr	Mo	N	Fe
1	AD30	.48	8.26	.21	.45	8.25	20.88	1.37	.22	Bal.
2	--	.50	7.90	.24	.31	7.86	20.00	1.23	.23	Bal.
3	--	.47	8.28	.23	.57	7.71	20.79	1.50	.16	Bal.
4	--	.49	7.60	.22	.45	7.91	18.22	1.25	.20	Bal.
5	--	.46	8.11	.17	.35	7.76	20.27	1.30	.23	Bal.

TABLE II

Details of welding procedures which gave satisfactory welds of AD30 type alloy

Manual Metallic Arc

Steel	Electrode	Polarity	Amperes
AD30	5/64 in. dia. type 310	Reversed	30-32
AD30	3/32 in. dia. type 312 mod.	Reversed	38-40
2	5/64 in. dia. type 310	Reversed	30-32
2	3/32 in. dia. type 312 mod.	Reversed	38-40
4	3/32 in. dia. type 312 mod.	Reversed	38-40

Manual Inert Gas Tungsten Arc

Steel	Electrode	Filler Wire	Polarity	Amperes	Gas
AD30	1/16 Thortung	AD30	Straight	40-42	6 cfh Argon
2	1/16 Thortung	2	Straight	40-42	6 cfh Argon

Automatic Inert Gas Tungsten Arc

Steel	Electrode	Filler Wire	Polarity	Amperes	Volts	Gas	Travel Speed
AD30	1/16 Thortung	- -	Straight	60	11	16 cfh Argon	10 ipm
AD30	1/16 Thortung	- -	Straight	80	11	16 cfh Argon	9 ipm

TABLE III

Mechanical Properties of Welded Specimens

a. Fusion Welds

Material solution treated 2150°F, 1/2 hr., air cool, prior to welding.
Material aged 1550°F, 16 hrs., air cool, after welding.
Material thickness: .06 in.

Steel	Welding Process	Electrode or filler	Tensile Strength psi	% Elong.	% R.A.
1	Metallic	Type 312 Mod.	132,500	1.0	4.1
1	Metallic	Type 312 Mod.	132,700	1.0	0.7
1	Heliarc	AD30	97,100	1.0	3.7
1	Heliarc	AD30	100,300	1.0	2.3
2	Metallic	Type 312 Mod.	155,300	2.5	2.5
2	Metallic	Type 312 Mod.	158,800	3.0	4.0
2	Metallic	Type 310	151,600	2.5	6.6
2	Metallic	Type 310	155,100	4.0	8.0
4	Metallic	Type 312 Mod.	132,300	1.0	1.5
4	Metallic	Type 312 Mod.	157,900	1.5	3.5

All specimens fractured through the weld metal.

b. Flashwelds(1)

Material solution treated 2150°F, 1/2 hr. air cool, prior to welding.
Material aged 1550°F, 16 hrs., air cool, after welding.
Material thickness: .375 in. diameter.

Steel	Welding Process	Tensile Strength	% Elong.
1	Flashweld	133,000	1.4
1	Flashweld	132,800	1.6
1	Flashweld	132,500	1.6
1	Flashweld	97,000	0.5
1	Flashweld	116,000	1.0

4 specimens fractured through the weld zone.
1 specimen fractured in parent metal.

(1) Tests performed by Battelle Memorial Institute.

TABLE IV

Short Time Tensile Tests on AD30 Sheet and Welds.

Material Thickness: .06 in.

	Testing Temp. °F	Tensile Strength psi	Elong. % in 2 in.
Heliarc Welded Samples AD30	1500	50,000	5.5
Filler Rod	1500	57,000	4.0
AD30 Sheet	1500	52,000	9.0

Samples solution treated 2150°F, 1/2 hr; aged at 1500°F, 16 hrs.; air cool.

TABLE V

Stress Rupture Properties of AD30 Sheet and Welds.

Material Thickness: .06 in.

	Test Temp. °F	Stress, psi	Rupture Life Hrs.	Elong. %	R.A. %
AD30 Welded Sample;	1200	55,000	129.4	4.4	1.7
Type 312 Mod. Electrode	1200	49,400	199.9	2.4	-
AD30 (a) Sheet	1200	55,000	436	0.9	0.3

Samples solution treated 2150°F, 1/2 hr; aged at 1500°F, 16 hrs.; air cool.

AD30 (a) analysis:	C	Mn	P	Ni	Cr	Mo	N
	.44	7.83	.24	7.71	19.52	1.20	.20

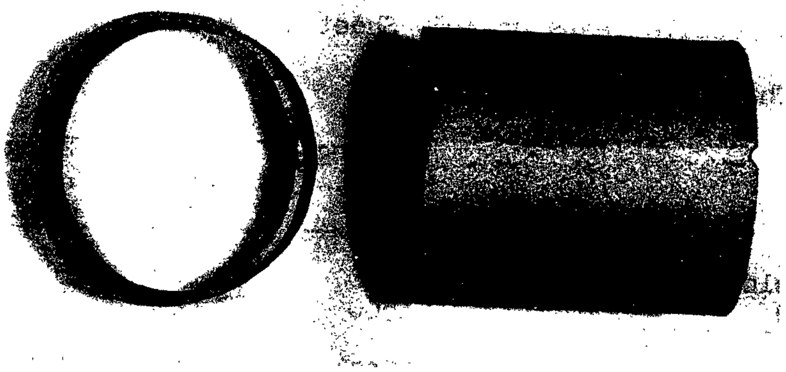

Figure 1 - Full Size

Longitudinal butt weld in AD30 sheet.
Joint design: square edge butt, zero root opening.
Welded by manual inert gas process,
no filler wire addition.

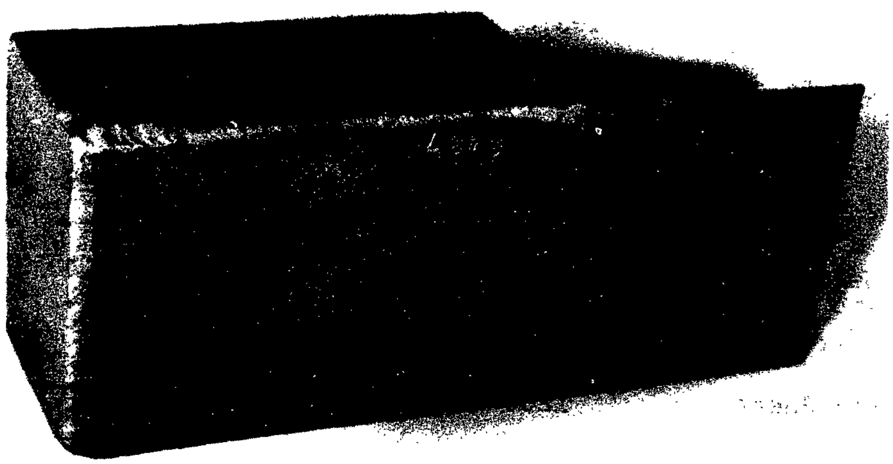

Figure 2 - Full Size

Edge joint weld in AD30 sheet.
Welded by manual inert gas process using AD30 filler.

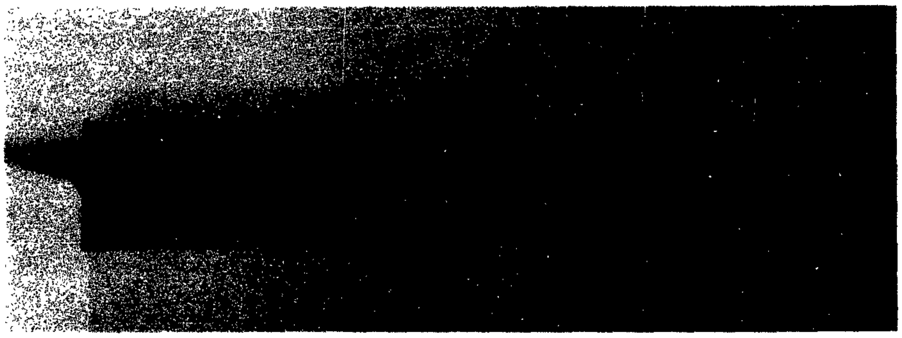

Figure 3 - Magnification 1/3 X

Double fillet weld in steel no. 4 (Table I).
Welded by manual metallic arc process using
3/32 in. dia. type 312 mod. (2-3% Mo) electrode.

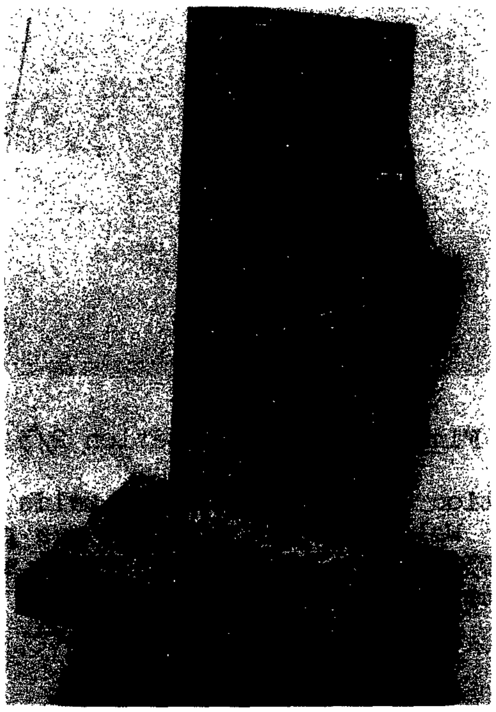

Figure 4 - Magnification 2/3 X

Double fillet weld joining .06 in. thick AD30 sheet
to 3/8 in. steel no. 3 (Table I). Welded by manual
Metallic arc using 3/32 in. dia. type 312 mod. (2-3% Mo) electrode.

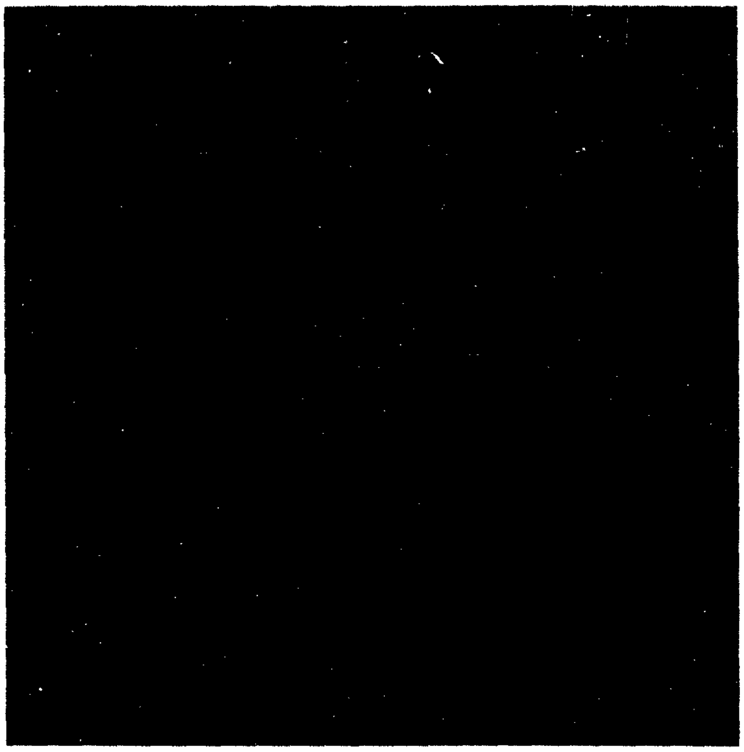

Figure 5 - Magnification 2/3 X

Combination of fillet and butt welds in AD30 sheet. Welded by manual inert gas process using AD30 filler. Section through a leg of weldment is semi-circular; weldment is not of tubular construction.

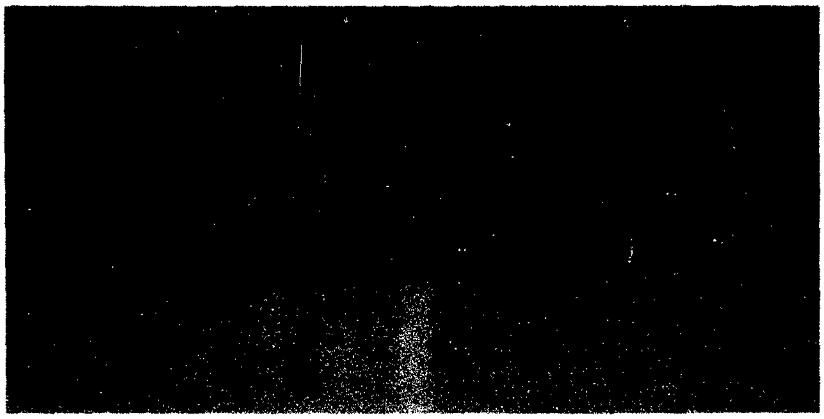

Figure 6a - Magnification 1/4 X

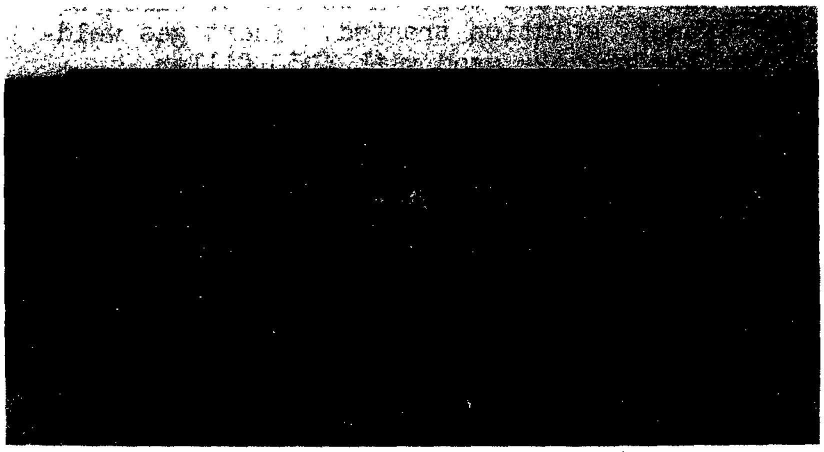

Figure 6b - Magnification 1/2 X

Fig. 6a - Longitudinal butt weld in tube of AD30 alloy. Tube is approximately 16 in. long, 4-1/2 in. I.D. and .06 in. wall. Welded by manual inert gas process, in two passes, using AD30 filler. Close up of weld is shown in Figure 6b.

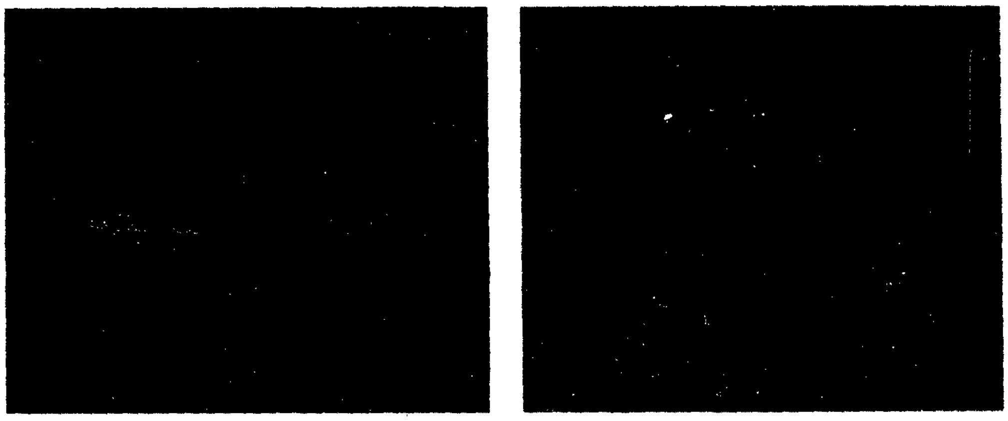

Figure 7 - Magnification Full Size

Face and root bend test on welded specimen of AD30 sheet, solution treated. Inert gas welding process used with AD30 filler.

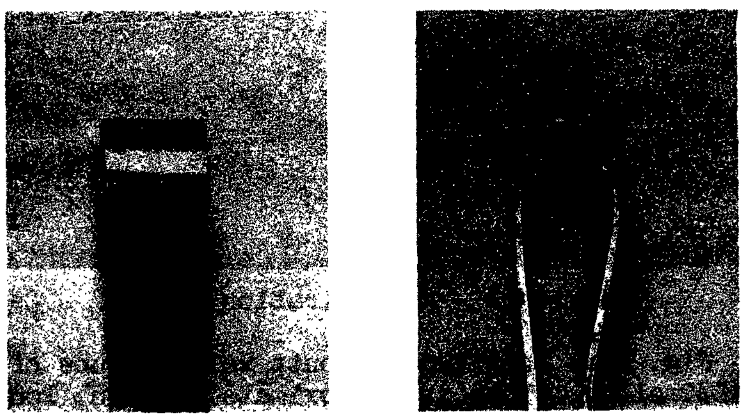

Figure 8 - Magnification Full Size

Root bend test on welded specimen of AD30 sheet, solution treated. Metallic arc welding process used with type 312 mod. electrode.

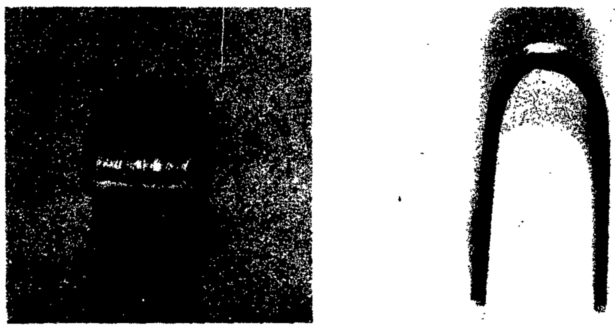

Figure 9 - Magnification Full Size

Face bend test on welded specimen of steel 5 (Table I), solution treated. Inert gas process used with no filler wire addition.

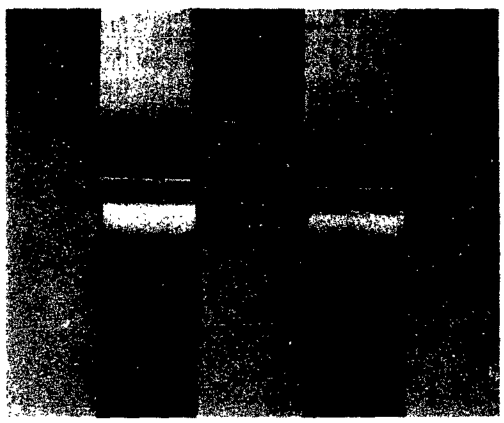

Figure 10 - Magnification Full Size

Face and root bend tests on welded specimen of AD30 steel, aged 1550°F, 16 hrs. after welding. Inert gas process used with AD30 filler.